403459

(5) 11 50
(7) NA (8) U
1 MAR 63
(11) NA (13) NA (14) NA
16 (17) (18) (19) NA
(20) U
(12) 16p. (9)

QUARTERLY TECHNICAL [redacted] NO. 3

PERIOD: Dec[redacted] 1, 1962- [redacted]
March 1, 1963

(6) CRYOGENIC STRETCH-FORMING OF
SOLID-PROPELLANT ROCKET CASES

Prepared for

(15) United States Army

Contract DA-30-069-ORD-3501

(10)

Prepared by: ______________ Approved by: ______________
George Claffy R. H. Alper
Project Engineer ARDEFORM Tech. Direct.

1 - AD-285944

TABLE OF CONTENTS

1.0 OBJECTIVE

The specific objective of the program is to produce experimental, flightweight rocket motor cases of the Pershing configuration, by the cryogenic stretch-forming process.

Previous work for the U. S. Army, under Contract DA-30-069-ORD-3099, demonstrated the feasibility of producing high-strength rocket cases by cryogenic stretch-forming. The present follow-on program is being undertaken to evaluate the process for producing a specific, predetermined, complex-configuration motor case at the strength level previously achieved (240,000 psi nominal yield stress). As can be seen in Figure 1, the Pershing motor case embodies, in one case, all of the features which might appear individually in various other cases. These include: elliptical head, thrust termination ports, skirts, conical aft closure, and nozzle attachment ring.

In manufacturing the Pershing case by cryogenic stretch-forming, ARDE-PORTLAND hopes to demonstrate that the process is a useful method for producing complex, high-strength rocket cases.

2.0 SUMMARY

Five vessel configurations (total of ten vessels) were cryogenically stretched prior to the occurrence of a breakdown in the stretch facility. Two of the configurations incorporated "dog-bone" components and were stretched as part of the program to develop the elliptical head. A simple vessel incorporating a thrust skirt, and two configurations for producing high-strength domes, were also stretched. Testing was interrupted due to a gross failure of the cryogenic pump of ~~ARDE-PORTLAND'~~s stretch facility. This failure curtailed stretch activities and delayed evaluation of several configurations. The pump was shipped to the manufacturer, who indicated that lengthy and expensive repairs were necessary. It was decided to scrap the old pump in view of the fact that a new, improved stretch facility would be complete before the old pump could be repaired. It is anticipated that the new facility will be in operation early in the next report period. With the cryogenic facility inoperative, a backlog of five preform vessels has built up, and these await stretching.

The computer program, for analytically determining the final shape to be achieved by cryogenically stretching a given preform vessel, was checked against actual data from a stretched vessel. The results indicate that the plasticity equations and the computer program are capable of predicting the stretched shape with a high degree of accuracy.

The first simple, full-size vessel was assembled during this report period and was rejected for bad welds. The problem proved to be one of dimensional tolerance on the head diameter. In this first try, the heads were purchased to ordinary vendor tolerances. With the resulting head-to-cylinder mismatch, it was not possible to make satisfactory girth welds on the vessel. Detail parts, with more closely matched dimensions, will be used for a second full-scale vessel.

2.0 (Cont'd)

A set of check-point drawings was provided to A.M.C., Redstone Arsenal. It will be recalled that these were suggested by the Project Officer during the previous report period to facilitate monitoring of progress on the various configurational features under development. A schedule of approximate target dates was provided along with the check-point drawings.

3.0 PERIOD ACTIVITY

3.1 Stretch Facilities: ARDE-PORTLAND's stretch facilities were inoperative at the end of this report period. A pump failure at the old stretch pit rendered that facility inoperative. The new, improved stretch pit is nearing completion, but is not yet ready for operation.

3.1.1 Old Stretch Pit: This pit has been used since the inception of the cryogenic stretch-forming program. It was initially designed to handle a limited number of small vessels. The pump is of the piston type and provides a maximum discharge pressure of 8000 psig with a very small flow capacity. The facility has been heavily overloaded due to requirements of an increased number of programs.

Recent testing with larger vessels has imposed continuous high-pressure conditions, and this resulted in a pump breakdown. The damage proved to be so extensive that at least a month would be required for repairs, at a very substantial cost. In view of the fact that the new stretch facility would be ready at the same time or earlier, it was decided to scrap the damaged pump and push the new facility to completion on an expedited basis.

3.1.2 New Stretch Pit: The new ARDE-PORTLAND stretch facility, now under construction, is designed to meet the requirements of larger vessels, higher stretch pressures, and higher fabrication rates. The pit will accommodate vessels up to a maximum diameter of approximately 65". Smaller vessels will be accommodated by means of smaller tanks inserted in the pit. Figure 3 is a view of the

3.1.2 (Cont'd)

new pit under construction with one of these small tanks installed for check-out runs. The shed in the background houses the two cryogenic pumps which will be used to pressurize vessels. One pump has a 4000 psig capability with a high flow capacity for larger vessels. The other pump can reach 30,000 psig and is intended for small heavy-walled vessels.

At the end of this report period, all hardware had been received, and all major components were installed. It is anticipated that the facility will reach operational status early in the next report period.

3.2 Vessels Stretched:

3.2.1 Elliptical-Head Effort: Two dog-bone configurations (four vessels) were stretched during the report period. These units were fabricated with hydroformed parts, duplicating two earlier configurations which utilized cone-and-disc construction. It will be recalled that the earlier vessels failed prematurely at the critical corner welds. Vessels #2034 and #2035, with annealed end plate, corresponded to Vessels #437 and #438 of the same configuration with cone-and-disc construction. Vessel #2034 sustained a high stress level failure through the start-stop position of the cone-to-cylinder weld. This is a rare type of failure which can be attributed to erratic settings during the weld decay period. Vessel #2035 reached design pressure in a cylindrical die, and the resulting head shape had a 1.34 ellipse ratio. Vessels #2036 and #2037 incorporated a half-hard, .080"-thick, 301 end plate in the same basic dog-bone shape. Both vessels achieved design pressure, one in a cylindrical die and the other "free-formed". Figure 2 shows the two vessels side by side after stretching. Free-formed Vessel #2036 proved to have a better ellipse ratio of approximately 1.45:1. It was found that the die restricted the growth of the extreme dog-bone diameter during stretching and thus permitted the head to grow outward at the apex, which reduced the ellipse ratio.

When Vessel #2037 was hydrotested after stretching, another interesting point regarding the die-stretched dog-bone was disclosed. The outermost portion of the dog-bone,

3.2.1 (Cont'd)

in the present design, did not stretch enough before reaching the die to strengthen adequately. Strain gages in this vicinity of the dog-bone reached a yield point at a pressure which brought the cylinder of the vessel to a stress level of only 166,000 psi--about 30% short of design strength. The results of these tests suggest a modification in dog-bone design which will be incorporated in future vessels. This new modification will consist of fabricating vessels with a smaller dog-bone diameter. The dog-bone will thus stretch a greater amount, thereby strengthening more and reducing the outward growth of head at the apex.

Other approaches to the elliptical head also progressed during the report period. Two types of vessels were stretched in an effort to obtain high-strength, large-radius-of-curvature domes. As mentioned in the previous quarterly report, such a dome can be welded to a stretched vessel with a hemispherical head which has been cut off to accommodate it. A restretch would smooth the structure into a flat, ellipsoidal head as well as strengthen the new weld.

Vessels #2015 and #2016 were special units consisting of two flat disc closures welded to a short cylinder 21 inches in diameter. The welds of such a vessel are very critical for stretching, but it was hoped that they would hold together to a cryogenic pressure sufficient to produce a fairly strong dome. Failures occurred at 100 psig for Vessel #2015 and 140 psig for Vessel #2016. Both failures occurred in the corner welds.

3.2.1 (Cont'd)

The feasibility of an alternate approach to the strengthened domes was demonstrated with Vessels #2028, #2029, and #2030. These were built by attaching two simple flanged-and-dished heads together with a girth weld. A pressurizing boss was welded into one of the heads. Buckling at the girth weld was expected, but the intent was to demonstrate that a substantial clean area around the apex of each head would become a strong dome with a large radius of curvature. All three vessels were successfully stretched, and the results indicate that the method is a practical one. It can be seen in Figure 4 that some buckling did occur at the girth weld, but the remainder of the heads are clean. The heads used for these vessels were readily available parts. Now that feasibility has been demonstrated, the experiment will be repeated with larger, flatter heads. This should be completed during the next report period.

In the first quarterly report, reference was made to pure longitudinal stretching as a possible mode of strengthening a vessel. It was reported at that time that the first attempt, with Vessel #2019, was unsuccessful due to excessive die friction. Since that time, the pure longitudinal stretch has been pursued with less emphasis, but the problem of reducing die friction was investigated during this report period. Two potentially useful coatings for the die, compatible with a temperature of -320°F, have been considered. These are molybdenum disulfide and teflon. The effect of either one would be to lubricate the inside of the cylindrical die and permit the vessel to stretch in spite of the high contact forces. The

3.2.1 (Cont'd)

longitudinal stretch is considered a lower priority back-up approach at this time. If this method is resumed actively, the above-mentioned coatings will be utilized to reduce the die friction.

3.2.2 <u>Skirt Attachment Technique</u>: The technique of welding a skirt to a stretched vessel and restretching to strengthen the weld zone was first demonstrated on a low-strength vessel. This technique was discussed in previous reports. Vessel #419 was used, and the strength level was 184,500 psi. During this report period, testing was completed on Vessel #2014, and results indicate that the technique is effective at the 240,000 psi strength level, which is the target for this program. A summary of the test data is tabulated below.

Initial Stretch Pressure	2400 psig	Hoop Stress 291,000 psi
Hydrotest Pressure @0.2% yield	1950 psig	Hoop Stress 236,000 psi
Restretch Pressure	2400 psig	
Hydrotest Pressure @0.2% yield	2000 psig	Hoop Stress 242,000 psi

It can be seen that the yield strength of the vessel was the same after adding the skirt and restretching as it was initially, within experimental accuracy. With the successful completion of this test, development work on the attachment of skirts is considered complete. It is now definitely planned to attach the skirts by welding after initial stretch, with a restretch to strengthen the weld.

3.2.3 <u>Port Attachment Technique</u>: Two approaches to the incorporation of ports are in progress. These are the integral-stretch method and the weld-and-restretch method.

3.2.3 (Cont'd)

During this report period, vessels were fabricated to test both methods but could not be stretched due to the stretch facility breakdown. Vessels #2032 and #2033 were fabricated with simulated ports installed in a dog-bone type head. The dog-bone was designed to permit convenient port installation and thus facilitate a test of the integral approach. If this proves feasible, the dog-bone design must be adjusted to produce the proper head shape.

Vessel #2021 was also fabricated during the report period. This is a simple vessel, with hemispherical heads, which was given an initial cryogenic stretch and shown by hydrotest to have a yield strength of approximately 240,000 psi. Simulated ports were then welded into one head, and the vessel now awaits restretch to strengthen the welds.

All of the above-mentioned vessels will be stretched during the next report period, when the new stretch facility is operational.

3.2.4 Aft-Head Development: A modified dog-bone-shaped preform is being used to achieve the aft-head shape. The first design showed promise but encountered premature failures in Vessels #2002 and #2003. These vessels were built with the old-style rolled-and-welded cones, and the failures were associated with the critical corner welds. During this report period, vessels of the same geometry were built with hydroformed parts, eliminating the corner welds. These will be stretched during the next report period, and it is anticipated that design stress will be achieved with these vessels.

3.2.5 Simple Vessels: A number of simple cylindrical vessels with hemispherical heads were fabricated and stretched during the report period. They were built for evaluating some of the techniques discussed in the previous sections. The large-radius-of-curvature dome approach to the elliptical head involves cutting a portion from a stretched hemispherical head and replacing it with the strengthened dome. Such an experiment will be performed on two of the simple vessels referred to here. The other three vessels will be used for feasibility studies involving the welding of ports and skirts to the stretched vessels. Vessel #2024 was die-stretched, and is scheduled to be used for evaluating the attachment of a flush skirt. The forming stress for the five vessels is tabulated below:

Vessel No.	Forming Stress
2012	253,000 psi
2013	259,000 psi
2022	249,000 psi
2023	240,000 psi
2024	270,000 psi (approx.) (in die)

3.3 Analytical Effort: As previously reported, a computer program for analyzing the plastic behavior of a dog-bone preform has been set up. It had been hoped to de-bug the program during this report period and stretch a dog-bone to design pressure for comparison. Problems with stretch facilities delayed the stretch at design pressure. The program was de-bugged successfully, however, and it was decided to try it on an older dog-bone which had successfully reached a forming stress of approximately 80% of the design value. The unit used for this evaluation was Vessel #417, which ARDE-PORTLAND had stretched just prior to receiving the present contract. The vessel was stretched in stages and accurately measured at each interval. The vessel had ruptured through one of the corner welds in the final attempt to reach design stress, and the highest successful stretch pressure before failure was 2000 psig. This is equivalent to a cylinder stress level of approximately 220,000 psi. With this preform geometry and a stretch pressure of 2000 psi as inputs, the computer output was a final calculated shape for the stretched vessel. This theoretical shape was plotted for comparison with measurements of the actual vessel stretched at 2000 psig. The results correlated remarkably well, as can be seen in Figure 5. The measurement data from Vessel #417 can hardly be distinguished from the theoretical curve. The success of this analytical approach has been highly encouraging, and it now provides a valuable tool for current efforts at configuration development. It will now be possible to analyze a proposed preform shape before committing time and money to the actual hardware. It is anticipated that many of the adjustments in preform dimensions, which are necessary to achieve the target stretched shape, can be made on paper rather than with hardware. In light of the

3.3 (Cont'd)

performance of the computer program, all future preform designs will be checked out on the computer prior to fabrication.

A more complete discussion of the analytical procedures is in preparation and will be submitted in the next quarterly report.

3.4 Simple Full-size Vessel: The first full-size vessel was built to gain fabrication and handling experience in the Pershing size and demonstrate sound welds. The vessel was assembled during this report period. The final welds, which were the girth welds, proved to be unsatisfactory. It was learned in building this vessel that the diametral tolerances specified for the heads were too loose for proper match-up with the cylinder. Due to mismatch at the head-to-cylinder joints, erratic weld penetration resulted. This type of defect would be certain to cause an early failure if the vessel were stretched. Additional ASME-type heads are available, and the best-matched pair will be selected for another try at completing a simple full-size unit. The possibility of repair-welding the first vessel is also being considered. This work will proceed on a low-priority basis so as not to interfere with sub-scale configuration work.

3.5 <u>Check-Point Drawings</u>: At the request of the A.M.C. Project Officer, check-point drawings showing the various features of the motor case being developed were prepared. These were completed and delivered during the report period. The final check-point drawings was a complete drawing of the sub-scale case proposed for delivery.

The drawings were reviewed by A.M.C. and A.M.R.A. personnel during the report period and returned to ARDE-PORTLAND with comments and a request for a joint meeting at Paramus. This meeting was scheduled for 3/28/63, and a thorough review of the program status and the proposed vessel design is planned for this meeting.

4.0 WORK PROJECTED FOR THE NEXT QUARTER

It is anticipated that the following will be accomplished during the next quarterly report period:

4.1 The new stretch pit will reach operational status.

4.2 A joint meeting with A.M.C. and A.M.R.A. representatives will be held at Paramus.

4.3 Vessels testing both port attachment techniques will be stretched.

4.4 The aft-head preform configuration using hydroformed parts will be stretched.

4.5 The complete preform vessel for producing the final case will be analyzed on the computer.

APPENDIX

TABLE I

Chemical Analysis of 301 Stainless Steel, Heat #21550

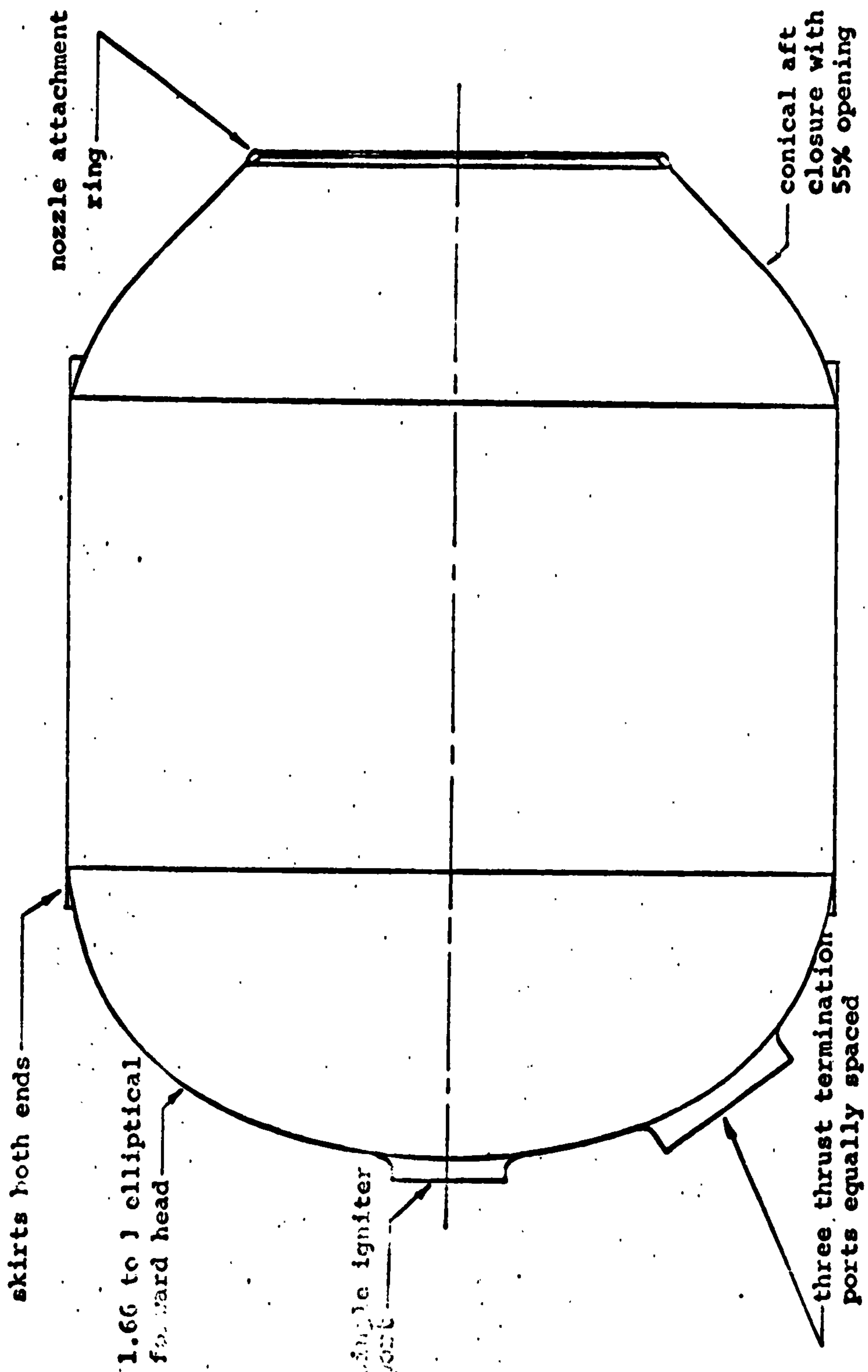
Element	% by Weight
C	.070
Mn	1.00
Si	.60
Cr	16.72
Ni	7.95
S	.011
P	.020

ARDE-PORTLAND, INC.

REPORT NO.____________ PAGE____________

JOB NO.____________

PREPARED BY____________ DATE____________



SKETCH OF THE PERSHING MOTOR CASE

FIGURE 1

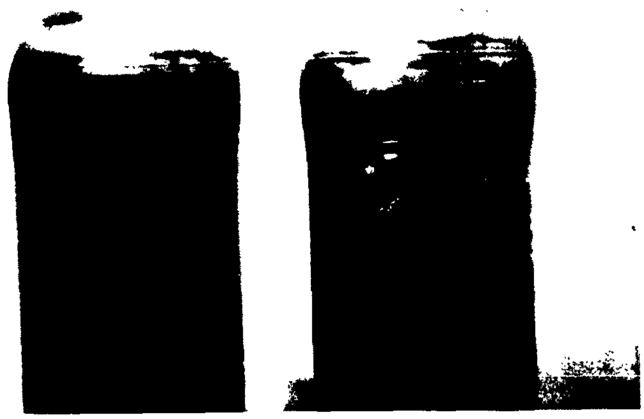


FIGURE 2 - Dog-Bone Vessels after Stretch

Vessel #2037, at left, was
stretched in die.

Vessel #2036, at right,
was stretched free-form.

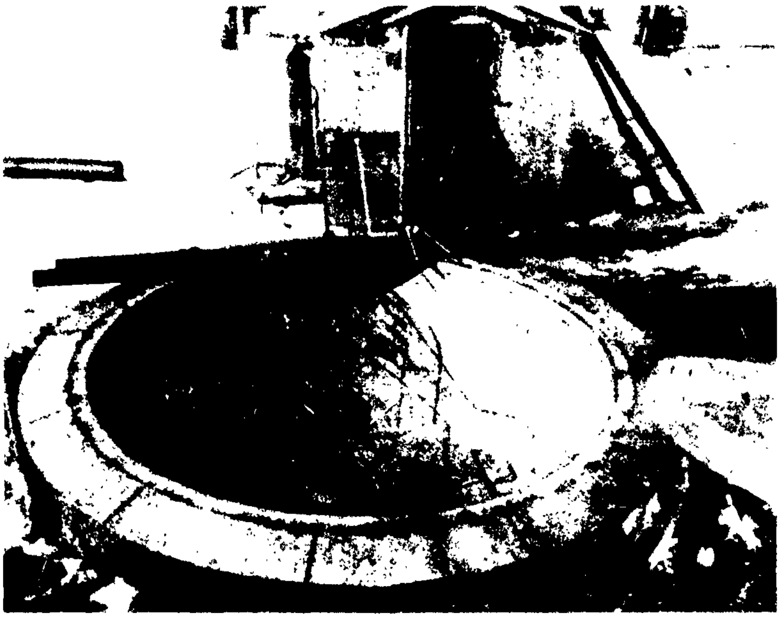


Figure 3 - View of New Facility Under Construction

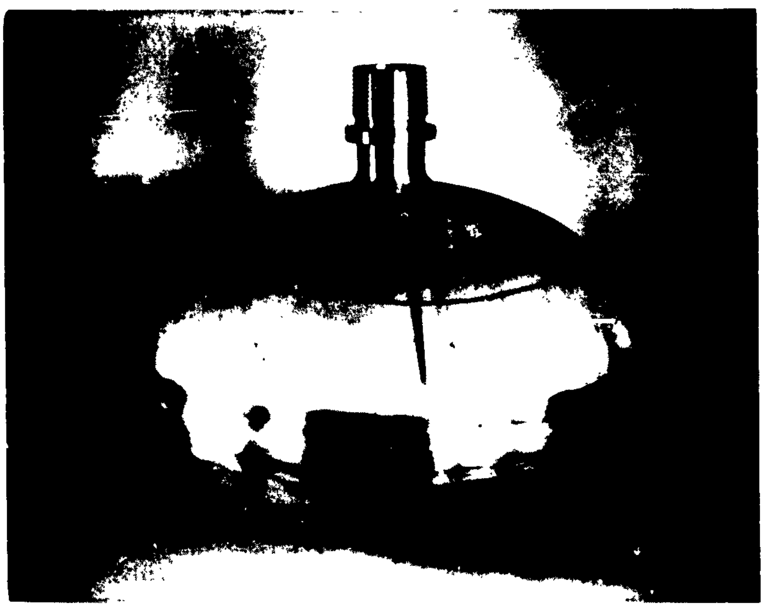


FIGURE 4 - Vessel #2030 after Stretch

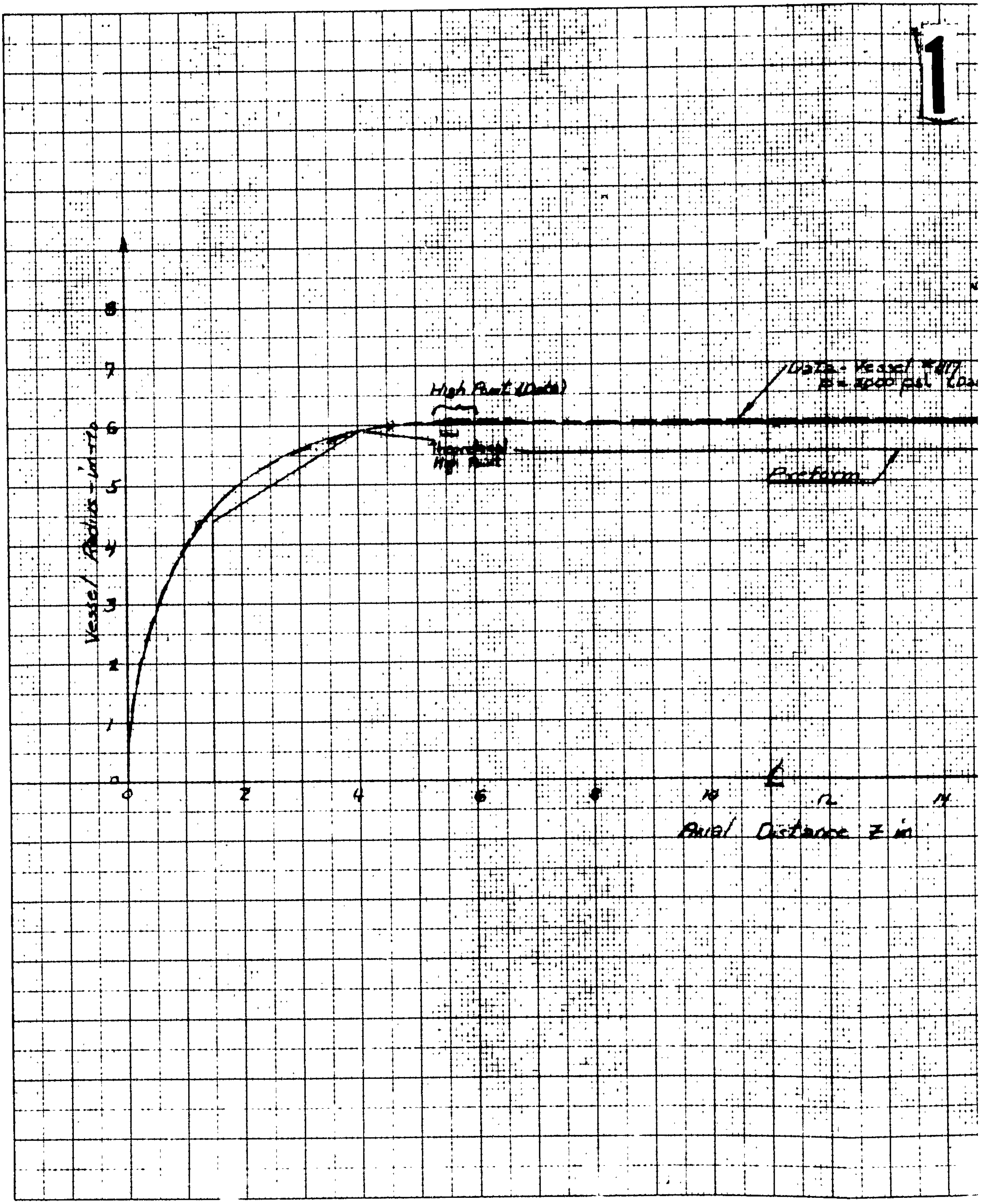
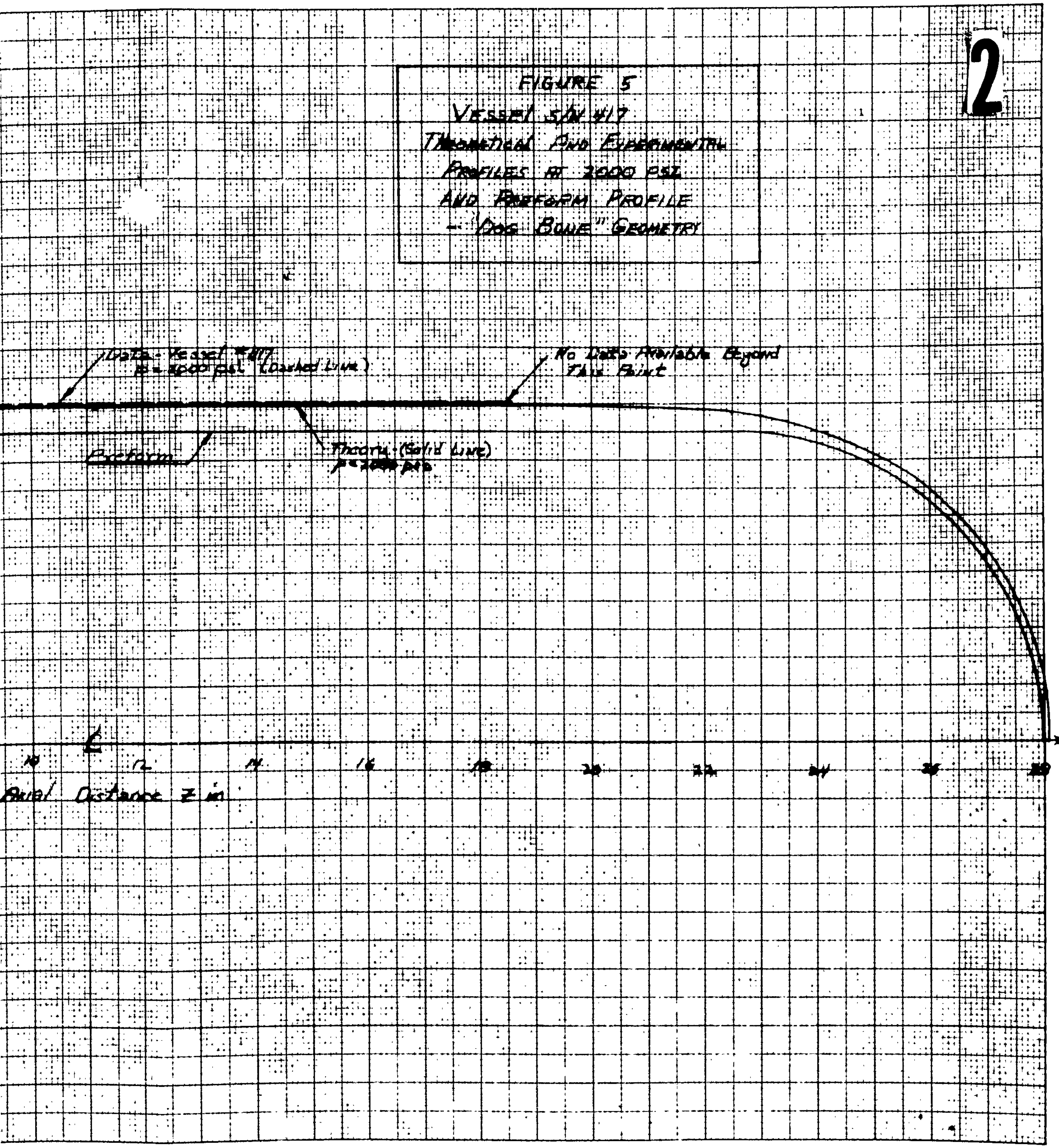

1
High Point (Data)
Data: Vessel #117
P = 3000 psi
Preform
Vessel Radius - in
Axial Distance Z in
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8

FIGURE 5
VESSEL S/N #17
THEORETICAL AND EXPERIMENTAL
PROFILES AT 2000 PSI
AND PREFORM PROFILE
– "DOG BONE" GEOMETRY



2